

## **Bookmarking the NDE Capability and Challenges Near the Dawn of the New Millennium**

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### **INTRODUCTION**

The Y2K marked the transition to the new Millennium with a concern of a computer design flaw that resulted from short sighting. While we are hesitating about the transition we can bookmark this point, look back with pride about what we accomplished in NDE and highlight the challenges to our field. NDE is now a relatively mature field and, even though accurate characterization of hidden flaws may still pose a challenge, the last century has been marked with the most incredible progress. The majority of the current NDE methods were introduced around the middle of this century and the modifications, improvements and enhancement that followed contributed to an unprecedented advancement in capability and reliability. Also, as an interdisciplinary field, NDE benefited from capabilities that were developed in many other fields of science and engineering. The resulting improvement touched every element of the NDE field leading to smarter instruments, which are computer-controlled, smaller, lighter and more capable. The requirements for NDE are continuing to be driven by the need for lower cost methods and instruments with greater reliability, sensitivity, user friendliness and high operation speed as well as applicability to complex materials and structures. The trend toward global market led to a growing recognition of the value of international standards covering test procedures and personnel qualification, where the documents issued by the International Standardization Organization (ISO) are becoming the leading ones. The NDE field growth is increasingly shifting into new frontiers as a result of defense budget cuts and shrinkage in government funding of research and development. Moreover, structures are being designed to require less periodic inspection using no fundamentally new material, and there is a lower need for new NDE methods to address such problems as aging aircraft. In this paper, the author made an attempt to summarize the status at the end of this Millennium and to identify the key NDE challenges.

The desire to nondestructively determine the quality and integrity of materials and structures has a very long history, where visual and tap testing have been the methods of choice for centuries. The introduction of the Magnetic Particles and Liquid Penetrant methods marked the transition to sophistication in NDE. Generally, it was well understood that any wave capable of traveling through a material is a candidate to be employed for an NDE method. The greatest progress was observed after effective data acquisition and display capabilities were developed to record and extract information about discontinuities and material properties. Around the middle of the Century, methods that rely on electromagnetic or elastic waves at various wavelengths were introduced at rapid rate. Fundamentally, these methods involve analysis of reflected and/or transmitted waves after interacting with the test part. The earlier methods have been Eddy Current and Radiography and were followed by Ultrasonics, Thermography and Holography. Later, during the 70's, Acoustic Emission, Magnetic Resonance Imaging (MRI) and Shearography emerged. In the absence of effective analytical tools prior to the 80's, the data

interpretation depended strongly on the experience and expertise of NDE personnel. In search for new capabilities, investigators sought correlation between various material variables and physical measurements. Some of the successful results are still being applied, e.g., the estimation of thermal treatment and hardness of metallic parts using conductivity measurements. One of the main objectives of the early studies has been to determine the strength of materials and bonded joints. Soon, it was recognized that while information about the integrity and stiffness can be extracted directly from NDE measurements, strength and durability cannot be measured by NDE methods because these are statistical and not physical properties. In order to establish sound foundations for NDE using theoretical models and analytical techniques, DARPA started to fund in the early 70's research and development studies of quantitative NDE. Since that time, conferences are being held annually to foster and strengthen collaborations and provide a forum for reporting progress among the NDE scientists and engineers. Advancement in computers, electronics, and improved analytical techniques led to significant progress in quantitative NDE. Finite element models are used to investigate the effect of flaws and the structure geometrical configuration on the wave behavior and the measured response. Also, inversion techniques are being developed to determine flaw characteristics from various wave measurements. Minute flaws can be detected at high probability and repeatability with less reliance on inspector capability, thus minimizing human errors. In recent years, there has been a growing technology transition of NDE methods to new areas, including medical diagnostics, geophysics, infrastructure, remote inspection, microelectronics, micro-electro-mechanical systems (MEMS), automation, etc.

In recognition of the potential benefit of synergistic interaction with other sciences and technologies, recent ASNT conferences have been increasingly including Sessions on interdisciplinary topics. Robotics, medical diagnostics and treatment, technology transfer, miniaturization and others are now common Session topics in the semi-annual ASNT conferences and the Annual ASNT Research Symposia. The NDE research community is continuing to have the objective to improve the capability of inspection methods to reliably detect critical flaws at lower cost with minimum impact on the serviceability and life cycle of the test structure. The topic of emerging technologies and challenges is very broad, and it is very difficult to thoroughly cover in a single paper. This manuscript is focused on the application to in-service NDE of aerospace structures.

## **EMERGING TECHNOLOGIES THAT ARE AFFECTING MULTIPLE NDE METHODS**

A series of advancements related to computers, electronics, material science and other interdisciplinary fields made major impact on all or many of the NDE methods. Accepting the reality that no single method can provide all the necessary NDE information, efforts are being made to integrate several methods. The complimenting capabilities offer greater detectability and the overlapping ones enhance the reliability. Data fusion techniques are being developed to allow effective data-acquisition and processing as well as provide a sound interpretation of the test parameters in relation to the material integrity. Instruments are now commercially available that can be used to perform ultrasonic and eddy current tests using a core hardware and interchangeable transducers and modules. Also, to support such systems capability, commercial software packages are available to process data obtained from various NDE methods. Once data is acquired, the image can be analyzed and manipulated using a common set of software features. The increased processing speed and improvement in hardware is allowing real-time imaging of

all the wave-base NDE methods including radiography, ultrasonics, shearography, etc. Using analytical tools, finite element analysis as well as computer hardware and software, test procedures can be developed graphically by interactive process simulation. Moreover, progress in microelectronics led to the development of miniature portable instruments that are pocket size. This section covers the technologies that affected the field of NDE in general and it will be followed by a review of specific development in the various inspection methods.

### **Information Highway**

In the relatively short time since Internet became the world-wide-web, this information highway contributed greatly to the advancement of many fields including NDE. Internet is now the information communication tool of choice for multimedia (data, files, text, programs, drawings, pictures, video and sound) at speeds, efficiency and content that cannot be matched by any other known method. NDE experts around the world rapidly recognized its power as a form of information exchange and archival. The technology is simplifying and helping to expedite the development of international standards and process specifications, as well as enabling the centralization and easing access of information achieves and databases. Formed in 1995, the global NDE Newsgroup [nde@coqui.ccf.swri.edu], which is maintained on a server at South West Research Institute, is widely used by NDE experts around the world as an electronic bulletin board. Subscribers are added electronically and they receive via e-mail inquiries, data, information and announcements of general interest. Global efforts and initiatives of individuals and companies are contributing greatly to the field. As an example, the electronic publishing forum, *NDT.net*, is a highly active and effective website that combines an electronic journal, information archive and monthly technical forums of information exchange [<http://www.ndt.net/newsweb/newsweb.htm>]. To take advantage of the various web capabilities the author formed the JPL's NDEAA webhub with clickable animation to aid understanding various mechanisms and with hotlinks to downloadable recent publications [<http://ndeaa.jpl.nasa.gov/>]. Moreover, to quickly find and access the growing number of homepages of international technical societies, the author formed the Global NDT Internet Superhub (GNIS) with clickable countries on a globe map [<http://eis.jpl.nasa.gov/ndeaa/nasa-nde/gnis/gnis.htm>]. The technology reached a point where "companies do not exist unless they have a homepage". To find some of the major homepage addresses, one can use the NTIAC webpage that has links to over 300 NDE site [<http://www.ntiac.com/>]. Through its homepages, ASNT is offering society information such as various services, conferences, and other relevant activity and announcements [<http://www.asnt.org/>].

### **Inspection Simulation**

Ray tracing has been a well-established tool for investigating the travel path of waves. With the progress and increased speed of computer graphics it became feasible to use ray tracing for the development of inspection procedures using rapid interactive simulation. Simulation software can perform 3D ray tracing, and examine the wave interaction with the test structure geometry while accounting for the material that is involved. Effective tools were developed by such research institutes as the Center for NDE at Iowa State University and the Canadian National Research Council as well as commercially by UTEX (Ontario, Canada). Computer models were used to develop user-friendly accurate and rapid simulation of such methods as radiography, ultrasonics, and eddy current. Numerous test parameters were included in the models, e.g., for X-ray simulation some of the parameters are X-ray source, film type, part geometry, setup

distances, exposure value, material absorption, etc. The part structure can be described using 3-D CAD models, and many types of defects can be inserted anywhere into the model to form a realistic simulation of the test process. In the case of modeling ultrasonics, the reflected, transmitted and refracted waves can be used to produce simulated A-, B-, and C-scans. Further, for eddy current the real and imaginary components of the impedance-plane output as a function of the probe position can be simulated in response to crack-like defects.

### **Miniaturization**

Progress in microelectronics enabled the miniaturization of NDE hardware and the production of portable instruments that can be carried to the field and reach difficult to access areas. Pocket size ultrasonic thickness gauges are commercially available from most of the leading manufacturers of ultrasonic instruments. The technology is leading to reduction in cost as well as in instrumentation weight and size with a great enhancement of the capability. Data acquisition cards that can be plugged into a laptop computer have been available for several years and credit card size plug-in that conform to the PCMCIA type 2 standard is one of the forms in which this progress is expressed. This type of cards allow making a laptop to a small ultrasonic pulser/receiver and with appropriate software it can be operated as a complete ultrasonic data acquisition and imaging system. Such cards can be used as motion control (encoder) interfaces, high resolution A/D converters and signal processors for portable scanners. The systems are battery operated and increasingly they are employing wireless communication capabilities. The technology of miniaturization has impacted also the size of sensors and their support electronics. For over ten years, the trucking industry has been using tires with imbedded sensors that wirelessly communicate every several minutes the individual tires' identity and pressure. Using effective power management, these sensors can operate for periods of more than 8 years without needing to change battery. This technology is intended to help truck drivers to avoid tragic and costly accidents that can result from a flat tire. Another area of automotive that benefited from the miniaturization technology is impact sensing and activation mechanism of airbags. Further, insects such as bees are commonly tracked with the aid of miniature transmitters that are installed as backpacks. Such capabilities can be transitioned to the field of acoustic emission and other NDE if miniature wireless stick-on sensors are used. The size of electronics has become so small that insects can be instrumented to perform tasks that used to be view as science fiction.

### ***NDE ISSUES AND CHALLENGES***

The continuing need for improved NDE methods resulted from the fact that each of the methods has certain capabilities and limitations with regards to detecting flaws and/or determining material properties. The selected method(s) and inspection requirements depend on the inspected material structural configuration and the life cycle stage. While in-service inspection of metallic structures require mostly the detection of fatigue cracks and corrosion, composites structures require the detection of delaminations and impact damage. Generally, unless a crack is located in a stack of plates beyond the second layer, many alternatives are available for its detection. Cracks need to be detected above a critical size and determine its size and depth. In contrast to this relatively simple requirement, corrosion detection and characterization and NDE of composite structures are more complex. Currently, there are several critical issues that are still challenging the NDE community with regards to inspection of composites. These issues include:

- Defect detection and characterization.

- Material properties characterization.
- Need for rapid large area inspection.
- Real-time health monitoring.
- Smart structures.
- Residual stresses.
- Weathering and corrosion damage

## CONCLUSIONS

As the 2<sup>nd</sup> Millennium is coming to an end, it is interesting to look back and see how far the field of NDE has been advanced so far and what are still the challenges. Like many other fields, improvements were made in every aspect of the NDE science and engineering where computers and internet contributed greatly to the rapid advancement. The various NDE methods were benefited with better inspection techniques. Also, efforts are increasingly being made to integrate several methods to form multi-mode systems that take advantage of the complementary capabilities to increase the functionality as well as the overlapping capabilities to improve the reliability.

Some technologies affected most or all the NDE methods and those include the use of computer graphics and interactive simulation to investigate the response of the specific methods. The effect of flaws on the wave response is analyzed using theoretical models and analytical tools, including finite element techniques. Also, inversion techniques are developed to extract flaw characteristics and material properties using nondestructive measurements.

Sensors can be divided into the following groups

- Remote sensors - Eddy current, magnetic, visual, dry-couple ultrasonics, etc.
- Attached sensors - Cracking fuse, resistance gauging, strain gage, acoustic emission, ultrasonic, eddy current, fiber optics
- Sensitive coating - Bruising paint indicator, brittle coating, liquid crystals
- Imbedded sensors - Fiber optics, dielectric, eddy current, magnetic, ultrasonics

The most practical sensors currently used are the ones that either operated remotely or attached to the test structures. The manufacturers and user are still not receptive to using sensors that are imbedded or permanently attached or coated. This is due to the addition in weight and the potential effect on the structural integrity. The use of stick-on wireless type sensors are expected to emerge in the coming years allowing to monitor structural integrity throughout structures life cycles without disassembly, redesign or complex wiring.

The use of the crawler technology, which was enabled by JPL, is offering great potential to rapid field inspection, where plug-and-ply boards would define the crawler functionality. Employing off-the-shelf components and standard personal computers bus structure (e.g., ISA, PCI etc.) can lead to a significant reduction in system cost. Currently, NDE hardware manufacturers have to develop a complete instrument each time a new product is introduced. It is envisioned that concentration on the development of components with focused NDE functionality (e.g., ultrasonics) will have great payoff. It would lead to substantially greater affordability of future instruments and to a faster transition of NDE technology to commercial use. Since the 96 ASNT Fall Conference, the author started holding Sessions on the topic of Robotics and Miniaturized NDT Instruments. The intent of these Sessions is to attract industry and academia attention to

the topic of developing generic mother-crawler and related plug-in modules. Recent government interest in addressing the issue of NDE of corrosion turned the spotlight onto MACS (JPL, Pasadena, CA) as a potential baseline for robotic multi-sensor platform for rapid scanning of aircraft structures. In future generations of this technology, micro-electronic mechanical systems (MEMS) is expected to lead to extremely small NDE instruments and scanners. Insect-size micro-scanners may potentially crawl into an aircraft engine and other hidden areas and perform inspection or other maintenance tasks.

Advancement in miniature electronics, actuators, robotics, wireless communication as well as sensors are expected to make great impact on the field of NDE in the coming years. The search for smarter methods that can rapidly and inexpensively detect very small flaws in complex materials and structures at very high probability and repeatability will continue to be a challenge for NDE. Efforts will be made to further reduce the complexity associated with inspection procedures, where redundant tasks will be performed by computers leaving the role of the human operator to critical decision making. While it is difficult to predict when, global standards will eventually be accepted worldwide and will cover all the NDE standards, inspection procedures and personnel training/qualifications.

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#### **REFERENCES**

- Y. Bar-Cohen, "In-Service NDE of Aerospace Structures -- Emerging Technologies and Challenges at the End of the 2<sup>nd</sup> Millennium." Submitted to the Material Evaluation in January 1999.